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RESEARCH MEMORANDUM

INVESTIGATION AT A MACH NUMBER OF 1.2 OF TWO

45° SWEPTBACK WINGS UTILIZING NACA 2-006

AND NACA 65A006 AIRFOIL SECTIONS

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FOR REFERENCE

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SUMMARY

An investigation has been made in the Langley low-turbulence pres-
sure tunnel at a Mach number of 1.2 to determine the lift, drag, and
moment characteristics of a wing employing an airfoil section designed
for high maximum lift at low speeds (NACA 2-006), and having 45° sweep-
back, aspect ratio 4, and taper ratio 0.6. A similar wing with the
NACA 65A006 airfoil section was also investigated to provide comparative
data. The lift, drag, and moment characteristics of the two wings were
found to be essentially the same at a Mach number of 1.2. Consequently,
the gains at low speed associated with the use of the NACA 2-006 section
can be obtained without penalty at Mach numbers of the order of 1.2, at
least for the type of wing plan form considered.

INTRODUCTION

In an attempt to improve the maximum-lift characteristics of thin
wings at low speeds, two new 6-percent-thick airfoil sections having
rather blunt leading edges were derived in reference 1. Section tests
of one of these airfoils (NACA 2-006) showed that a maximum lift coef-
ficient of about 1.3 was obtained at low Mach numbers, provided the
leading edge was maintained in a smooth condition. The results of a
subsequent investigation of a semispan wing with 45° sweepback, aspect
ratio 4, and taper ratio 0.6 indicated that the use of the NACA 2-006
airfoil section as compared to the NACA 65A006 airfoil section improved
the lift and pitching-moment characteristics at low speeds without
causing much change in the high-speed characteristics up to a Mach num-
ber of 0.95 (ref. 2).

The characteristics of typical high-speed wing plan forms employing the new sections are needed, however, for the transonic and low-supersonic speed ranges. In partial fulfillment of this need, the same two wings considered in reference 2 have been tested at a Mach number of 1.2.

The investigation consisted of measurements of the lift, drag, pitching-moment, and root bending-moment characteristics at Reynolds numbers of 1.0×10^6 and approximately 3.0×10^6 with the models in the aerodynamically smooth condition. The results of the investigation are reported herein.

SYMBOLS

C_L lift coefficient, $\dfrac{\text{Twice model lift}}{qS}$

$C_{L_{max}}$ maximum lift coefficient

C_{L_s} highest lift coefficient reached before unstable pitching-moment break

C_D drag coefficient, $\dfrac{\text{Twice model drag}}{qS}$

$C_{D_{min}}$ minimum drag coefficient

$C_{m_{\bar{c}/4}}$ pitching-moment coefficient measured about quarter chord of wing mean aerodynamic chord, $\dfrac{\text{Twice model pitching moment}}{qS\bar{c}}$

C_B wing-root bending-moment coefficient, $\dfrac{B}{q\dfrac{S}{2}\dfrac{b}{2}}$

B bending moment at wing root, ft-lb

q free-stream dynamic pressure, $\frac{1}{2}\rho V_0^2$, lb/sq ft

ρ free-stream mass density, slugs/cu ft

V_0 free-stream velocity, ft/sec

V local velocity, ft/sec

S twice area of model, 2.778 sq ft

b   twice model semispan, ft

$\bar{c}$ mean aerodynamic chord, $\dfrac{2}{S}\displaystyle\int_0^{b/2} c^2 db$, ft

x   distance along chord

y   distance normal to chord

c   wing chord at any spanwise station parallel to plane of symmetry, ft

α angle of attack of wing-root-chord line, deg

R   Reynolds number based on mean aerodynamic chord

M   free-stream Mach number, V_O/a_O

a_O free-stream speed of sound, ft/sec

APPARATUS AND TESTS

Apparatus.- The present investigation was conducted in the Langley low-turbulence pressure tunnel (ref. 3) which has a test section 3 feet wide by 7.5 feet high. Originally, this wind tunnel was operated as a low-speed high Reynolds number facility. Alterations have been made to the tunnel, however, which permit the use of Freon-12 as a test medium in which choking Mach numbers can be obtained in the tunnel test section (ref. 4). More recently, the vertical walls of the tunnel were temporarily altered to conform to a Laval nozzle to produce a Mach number of 1.186 in Freon. The corresponding Mach number in air is 1.2. The maximum Mach number variation along the tunnel test section was 0.9 percent of the free-stream Mach number.

For the present investigation, a balance equipped with electrical strain gages was used to measure the lift, drag, pitching moment, and root bending moment of a semispan model. The end of the model extending beyond the plane of symmetry passed through the tunnel wall and was attached to the balance as shown in figure 1. A labyrinth type of seal was used to minimize the effects of leakage through the slot in the tunnel wall. Unpublished data have shown that the force characteristics are unaffected by the small amount of leakage that occurs through the seals.

Models.- The models tested were the same as those employed for the investigation reported in reference 2. The models were constructed of aluminum alloy and had 45° sweepback measured at the quarter-chord line, aspect ratio 4, and taper ratio of 0.60; one model had NACA 65A006 air-foil sections, the other had NACA 2-006 airfoil sections. The airfoil sections were laid out parallel to the plane of symmetry. The dimensions of the model and a photograph of the model mounted in the tunnel test section are presented in figures 2 and 3, respectively. Ordinates for the airfoil sections are presented in table I. A sketch showing the profile and incompressible theoretical pressure distributions at zero lift of the NACA 2-006 airfoil section as compared with those of an NACA 65A006 airfoil section is presented in figure 4.

Tests.- Measurements were made of the aerodynamic characteristics at a Mach number of 1.2 for Reynolds numbers of 1.0×10^6 and approximately 3.0×10^6. The lift, drag, pitching moment, and root bending moment were determined at angles of attack from $-4°$ to $30°$ for the wing employing the NACA 2-006 airfoil section and from $-4°$ to $20°$ for the wing employing the NACA 65A006 airfoil section. It is believed that the data are free of any interference effects which would result from movement of the normal shock into the tunnel test section at large angles of attack.

Precision of measurements and corrections.- As estimated from the sensitivity of the balance, the error in the lift, drag, pitching-moment, and root bending-moment coefficients for the models tested in this investigation should be less than 0.005, 0.002, 0.001, and 0.005, respectively, at a Reynolds number of 1.0×10^6 and less than 0.003, 0.001, 0.0005, and 0.003, respectively, at a Reynolds number of 3.0×10^6.

Because of small differences in dynamic pressure and the same wing plan forms employed, the comparisons of the data presented herein are probably unaffected by aeroelasticity.

The data obtained in Freon were corrected to equivalent air data by means of an analysis of the type presented in reference 4 but based on results obtained in both Freon and air at a Mach number of 1.2.

RESULTS AND DISCUSSION

The wing employing the NACA 2-006 airfoil section is referred to as wing 1 and the wing employing the NACA 65A006 airfoil section as wing 2.

Lift and pitching moment.- The data of figures 5 and 6 show that the lift and pitching-moment characteristics of both wings 1 and 2 are

independent of variations in Reynolds numbers between 1.0×10^6 and 3.0×10^6 or 3.5×10^6 except for small changes in the pitching-moment coefficient at lift coefficients above 0.6. In order to aid in comparing the lift and pitching-moment characteristics of the two wings at a Mach number of 1.2 and a Reynolds number of approximately 3.0×10^6, some of the data presented in figures 5 and 6 have been replotted in figure 7. These data indicate only small differences in the lift and moment characteristics of the two wings. The maximum lift coefficient and lift-curve slope may perhaps be somewhat higher for wing 1 (NACA 2-006) than for wing 2 (NACA 65A006), and the highest lift coefficient reached before the unstable break in the pitching-moment curve C_{L_S} occurred at a lift coefficient about 0.08 lower for wing 1 as compared to wing 2. It should be noted, however, that for a Reynolds number of 1.0×10^6, the values of C_{L_S} are approximately the same for wings 1 and 2.

In order to compare the wings throughout the range of Mach number for which data are available, some of the subsonic results presented in reference 2 for a Reynolds number of 5×10^6 have been presented in figure 8 together with the values of C_{L_S} obtained in the present investigation at a Mach number of 1.2 and a Reynolds number of approximately $3. \times 10^6$. Values of maximum lift coefficient are not included in figure 8 for a Mach number of 1.2 because of uncertainty as to whether maximum values were actually obtained, particularly for wing 2. The data of the present investigation together with those of reference 2 indicate that the difference in the lift coefficient corresponding to the unstable pitching-moment break of wings 1 and 2 is less than 0.1 at a Mach number of 1.2; whereas at low speeds, the values of C_{L_S} and $C_{L_{max}}$ for wing 1 are 0.3 and 0.1 higher, respectively, than for wing 2.

Drag.- Figures 5(a) and 6(a) indicate that the drag characteristics of wings 1 and 2 are unaffected by variations in Reynolds number between 1.0×10^6 and 3.0×10^6 or 3.5×10^6. Within the accuracy of the data, the drag characteristics of the two wings are seen in figure 7(a) to be essentially the same for values of the lift coefficient up to about 0.4. For a short range of lift coefficient above about 0.4, the drag of wing 1 seems to be slightly higher than that of wing 2. The lift-drag ratio, shown in figure 7(b) as a function of lift coefficient, appears to be about the same for both wings at all lift coefficients.

A comparison of the minimum-drag characteristics and of the drag at a lift coefficient of 0.4 for the two wings for Mach numbers of 0.1 to 0.93 and 1.2 is shown in figure 8(b). The data for Mach numbers of 0.1 to 0.93 are taken from reference 2. Although these data cannot be relied

upon at Mach numbers below 0.5, because of the insensitivity of the balance, the data at subsonic Mach numbers above 0.5 indicate that the minimum drag coefficients of wing 1 were somewhat greater than those of wing 2; at a Mach number of 1.2, however, the minimum drag coefficients of wings 1 and 2 are the same. The drag coefficients at a lift coefficient of 0.4 are lower for wing 1 than for wing 2 at Mach numbers below 0.85, and at a Mach number of 1.2, the drag coefficients of the two wings are again essentially the same.

Root bending moment.- The root-bending-moment data for wings 1 and 2 are presented in figures 5(b) and 6(b). A comparison of the center-of-pressure characteristics of wings 1 and 2 determined from the root-bending-moment data is presented in figure 7(b). These data indicate that the variation of the position of the center of pressure is about the same for both wings above a lift coefficient of 0.4, but for smaller values of the lift coefficient there are some differences. These differences are unimportant in view of the small magnitude of the lift coefficient.

CONCLUDING REMARKS

An investigation has been made in the Langley low-turbulence pressure tunnel at a Mach number of 1.2 to determine the lift, drag, and moment characteristics of a wing employing an airfoil section designed for high maximum lift at low speeds (NACA 2-006) and having 45° sweepback, aspect ratio 4, and taper ratio 0.6. A similar wing with the NACA 65A006 airfoil section was also investigated to provide comparative data.

The lift, drag, and moment characteristics of the two wings were found to be essentially the same at a Mach number of 1.2. The gains at low speed associated with the use of the NACA 2-006 section can therefore be obtained without penalty at Mach numbers of the order of 1.2, at least for the type of wing plan form considered in the present investigation.

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REFERENCES

1. Loftin, Laurence K., Jr., and Von Doenhoff, Albert E.: Exploratory Investigation at High and Low Subsonic Mach Numbers of Two Experimental 6-Percent-Thick Airfoil Sections Designed to Have High Maximum Lift Coefficients. NACA RM L51F06, 1951.

2. Racisz, Stanley F., and Paradiso, Nicholas J.: Wind-Tunnel Investigation at High and Low Subsonic Mach Numbers of a Thin Sweptback Wing Having an Airfoil Section Designed for High Maximum Lift. NACA RM L51L04, 1952.

3. Von Doenhoff, Albert E., and Abbott, Frank T., Jr.: The Langley Two-Dimensional Low-Turbulence Pressure Tunnel. NACA TN 1283, 1947.

4. Von Doenhoff, Albert E., and Braslow, Albert L.: Studies of the Use of Freon-12 As a Testing Medium in the Langley Low-Turbulence Pressure Tunnel. NACA RM L51I11, 1951.

TABLE I

ORDINATES FOR THE AIRFOIL SECTIONS

NACA 2-006

x (percent c)	y (percent c)
0	0
.501	.937
2.008	1.769
4.541	2.413
8.114	2.818
12.717	2.983
18.292	2.962
24.727	2.810
31.828	2.561
35.000	2.442
40.000	2.254
45.000	2.066
50.000	1.878
55.000	1.691
60.000	1.503
65.000	1.315
70.000	1.127
75.000	.939
80.000	.751
85.000	.564
90.000	.376
95.000	.188
100.000	0

L.E. radius: 0.805 percent c

NACA 65A006

x (percent c)	y (percent c)
0	0
.500	.464
.750	.563
1.250	.718
2.500	.981
5.000	1.313
7.500	1.591
10.000	1.824
15.000	2.194
20.000	2.474
25.000	2.687
30.000	2.842
35.000	2.945
40.000	2.996
45.000	2.992
50.000	2.925
55.000	2.793
60.000	2.602
65.000	2.364
70.000	2.087
75.000	1.775
80.000	1.437
85.000	1.083
90.000	.727
95.000	.370
100.000	.013

L.E. radius: 0.229 percent c
T.E. radius: 0.014 percent c

Semispan balance chuck

Bakelite insulation

Labyrinth seal (brass)

Tunnel wall

Plaster

Rotating end plate

Model

Air stream
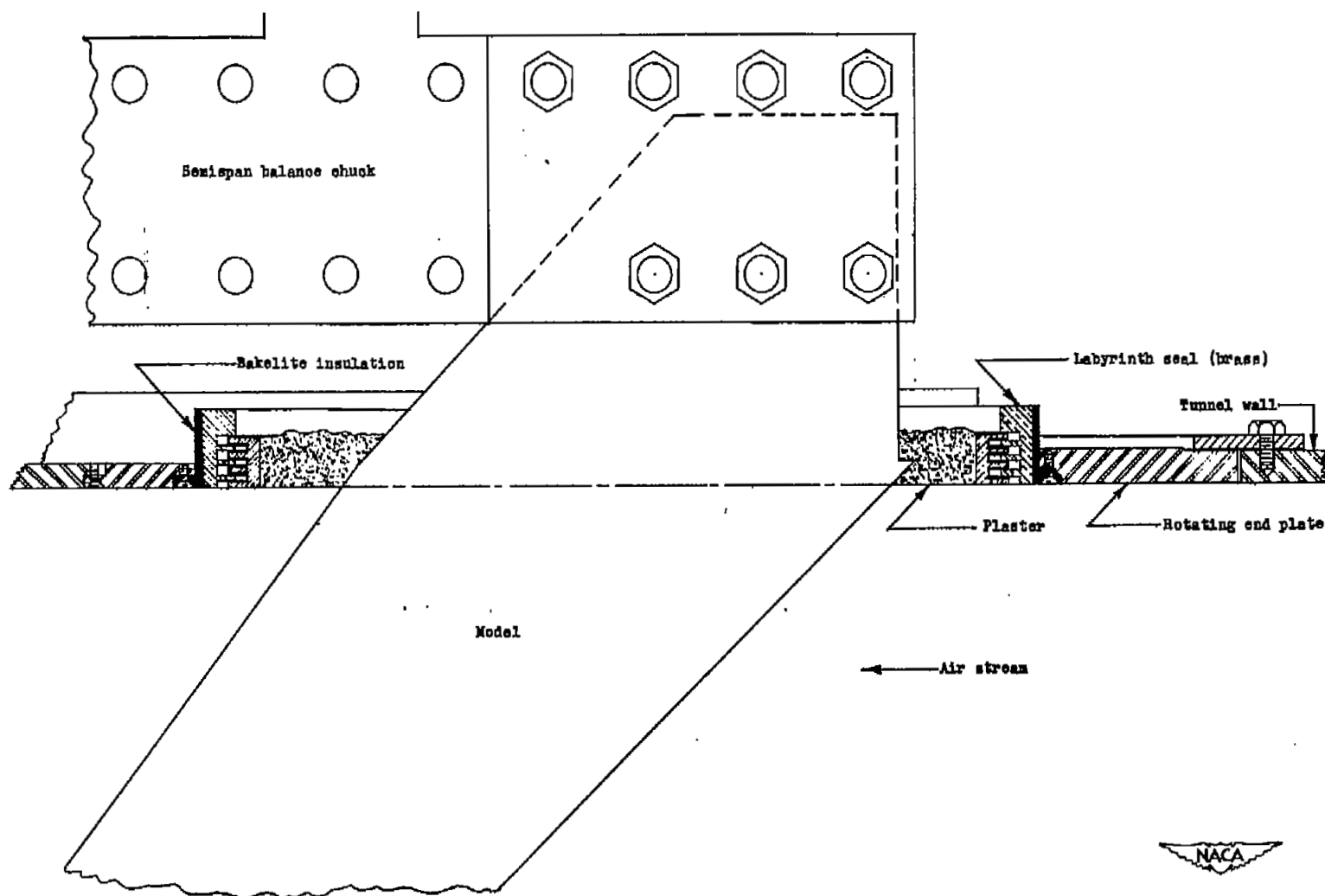
Figure 1.- Method of mounting model on semispan balance.
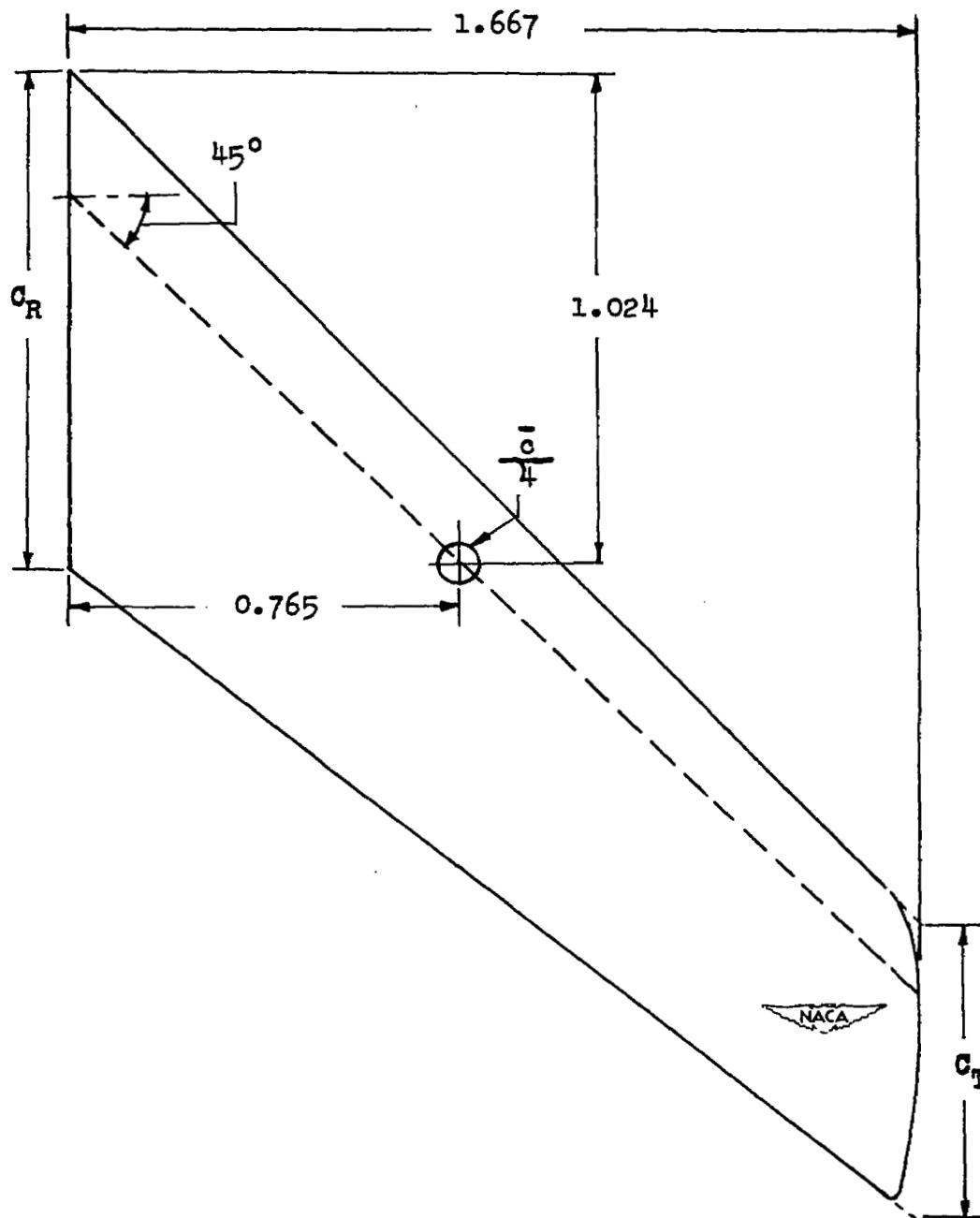
Figure 2.- Sketch of the wing plan form.   All dimensions are in feet.
$\frac{C_T}{C_R} = 0.6$; $\bar{c} = 0.851$ foot; $\frac{S}{2} = 1.389$ square feet.
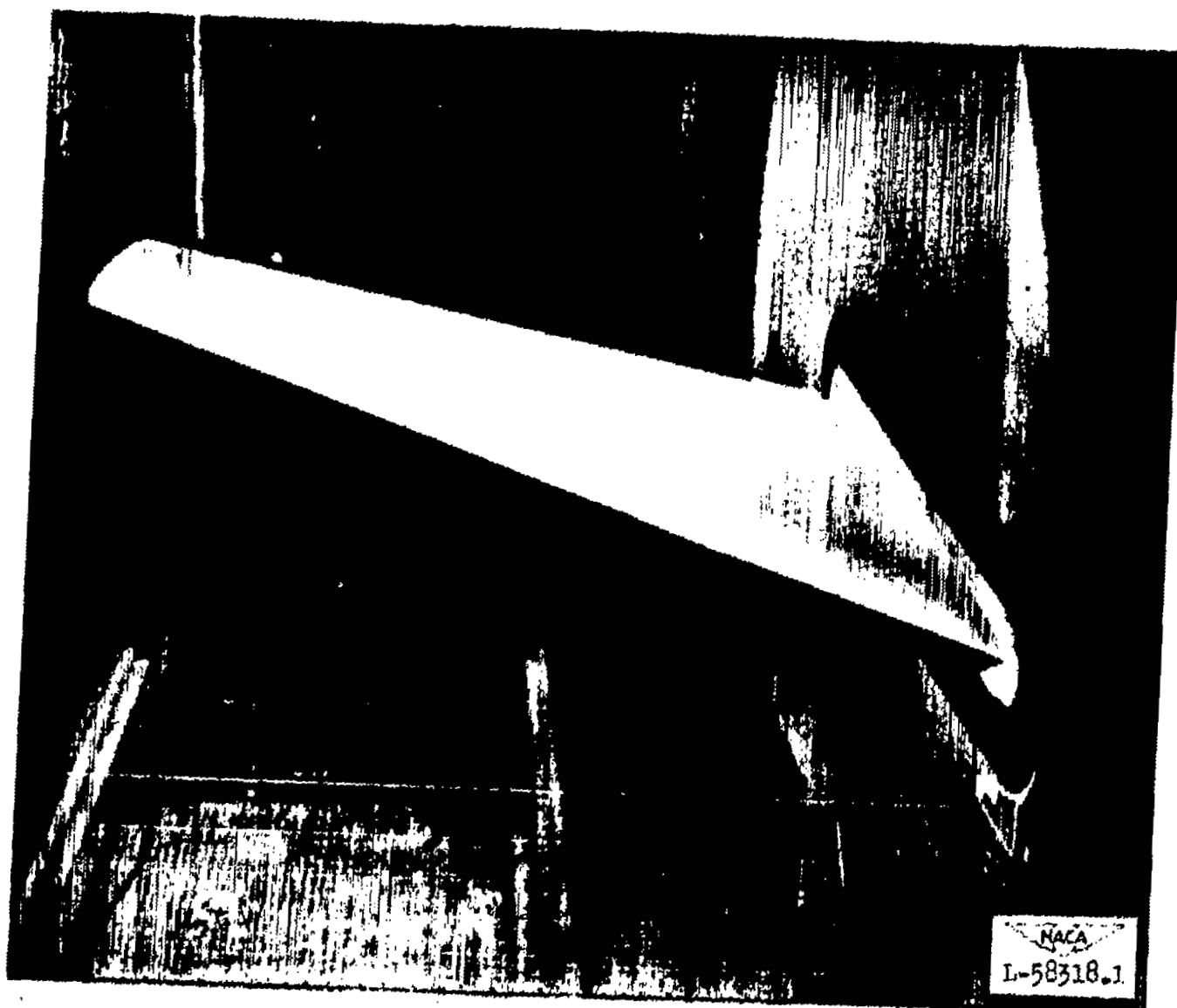
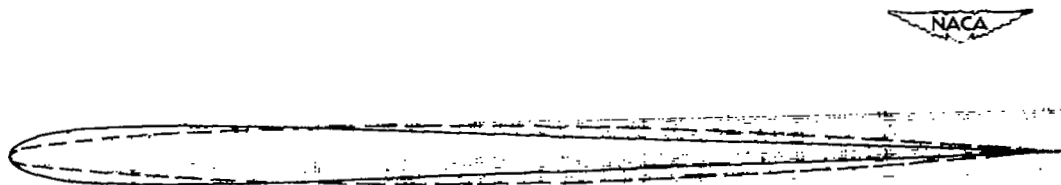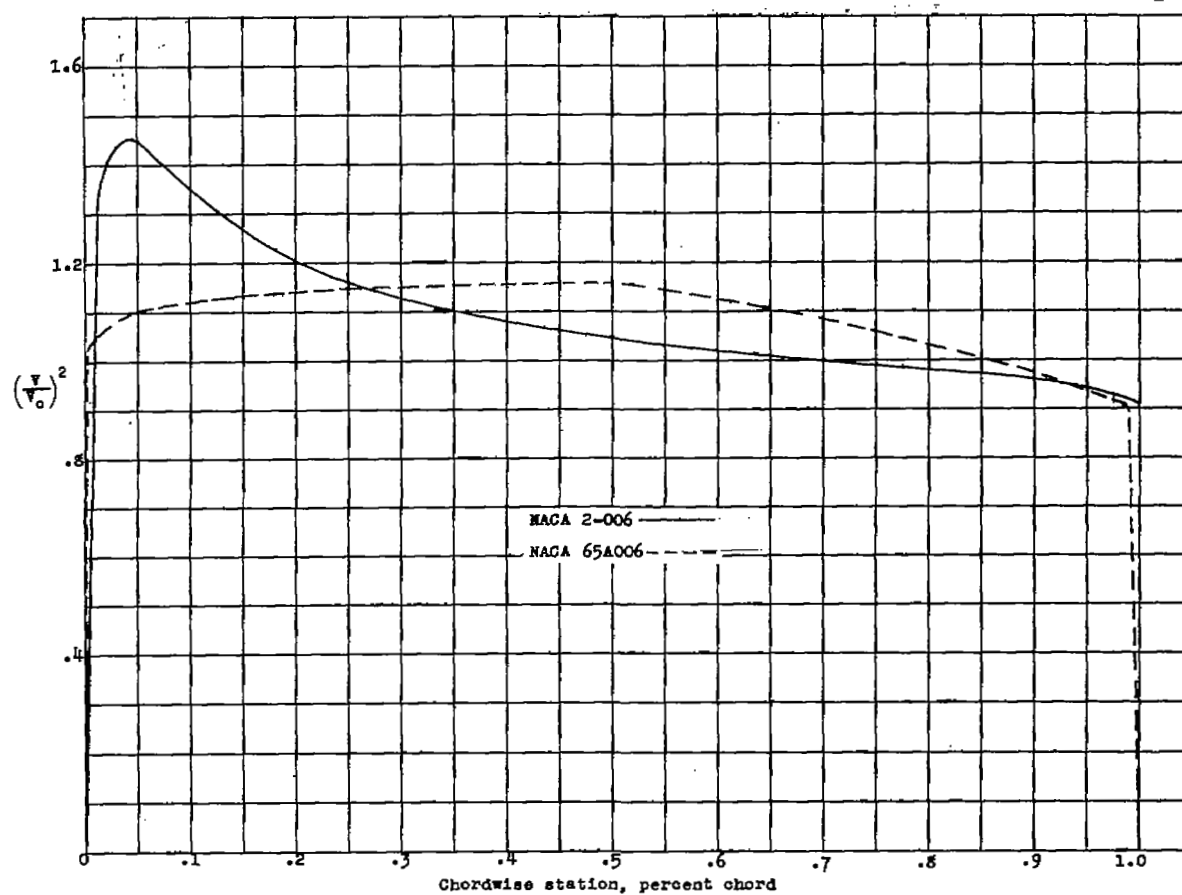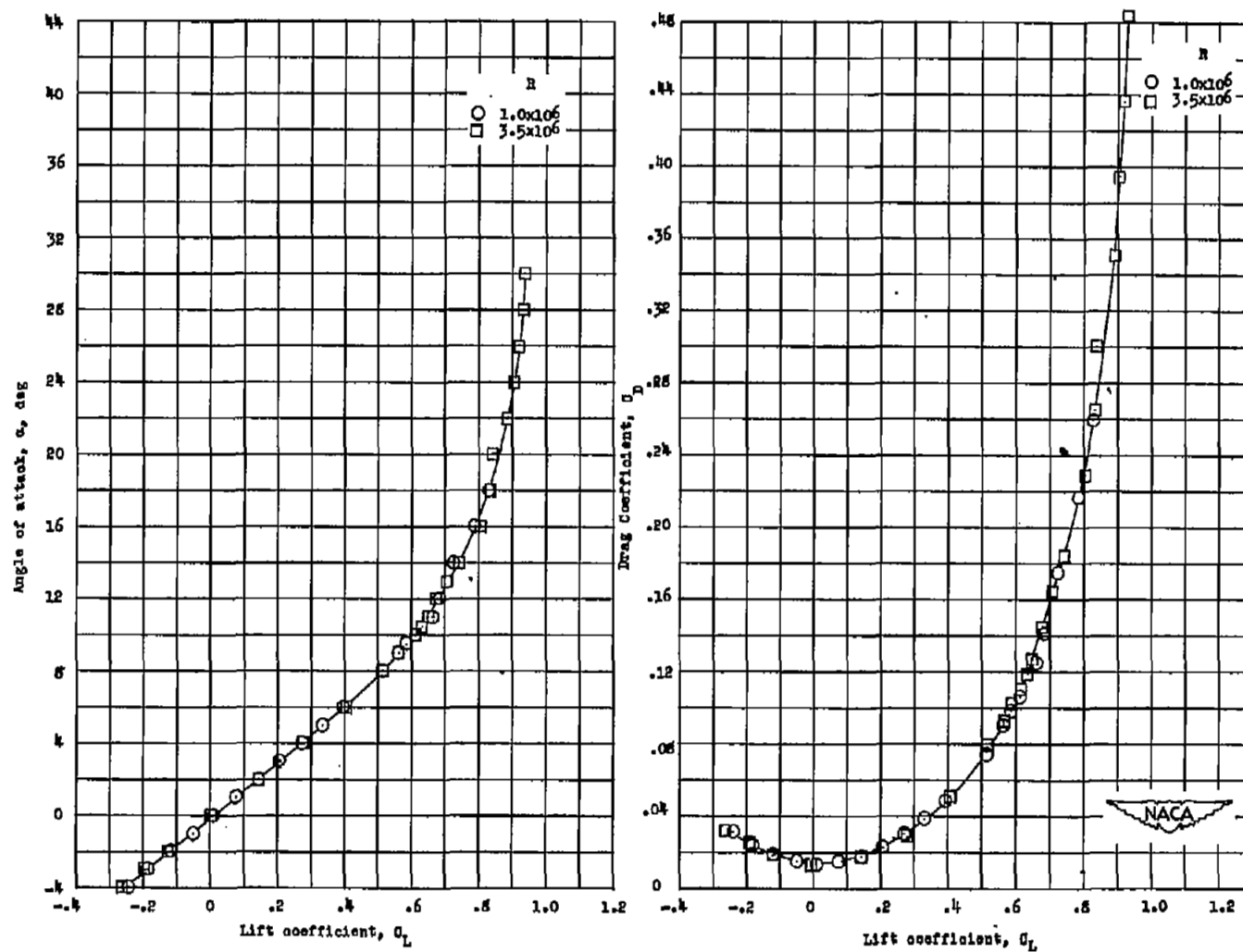Figure 3.- One of the models in the Langley low-turbulence pressure tunnel.

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Figure 4.- Incompressible theoretical pressure distribution at zero lift and airfoil profiles for the NACA 2-006 and NACA 65A006 airfoil sections.
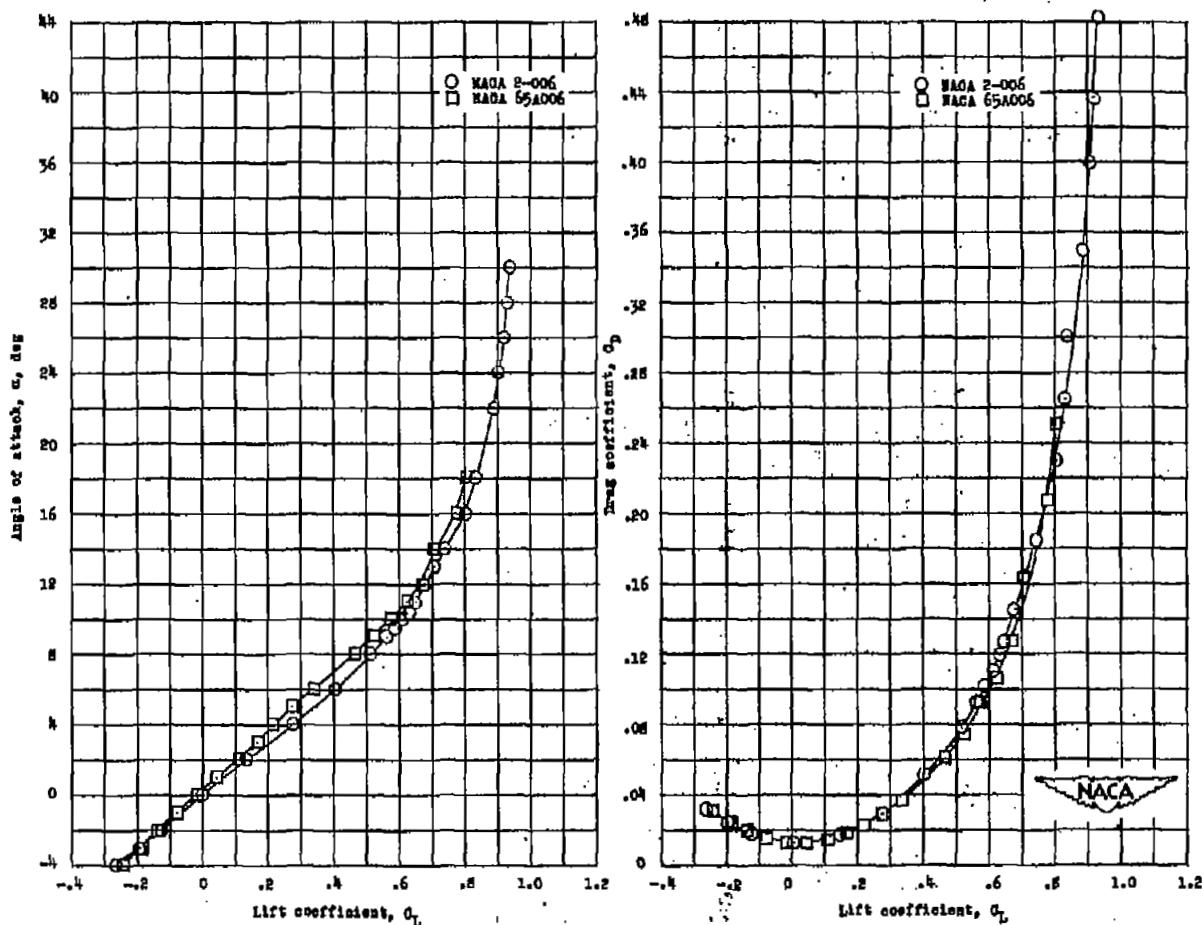
(a) Angle of attack and drag.

Figure 5.- Aerodynamic characteristics of the wing with the NACA 2-006 air-
foil section for two Reynolds numbers at a Mach number of 1.2.
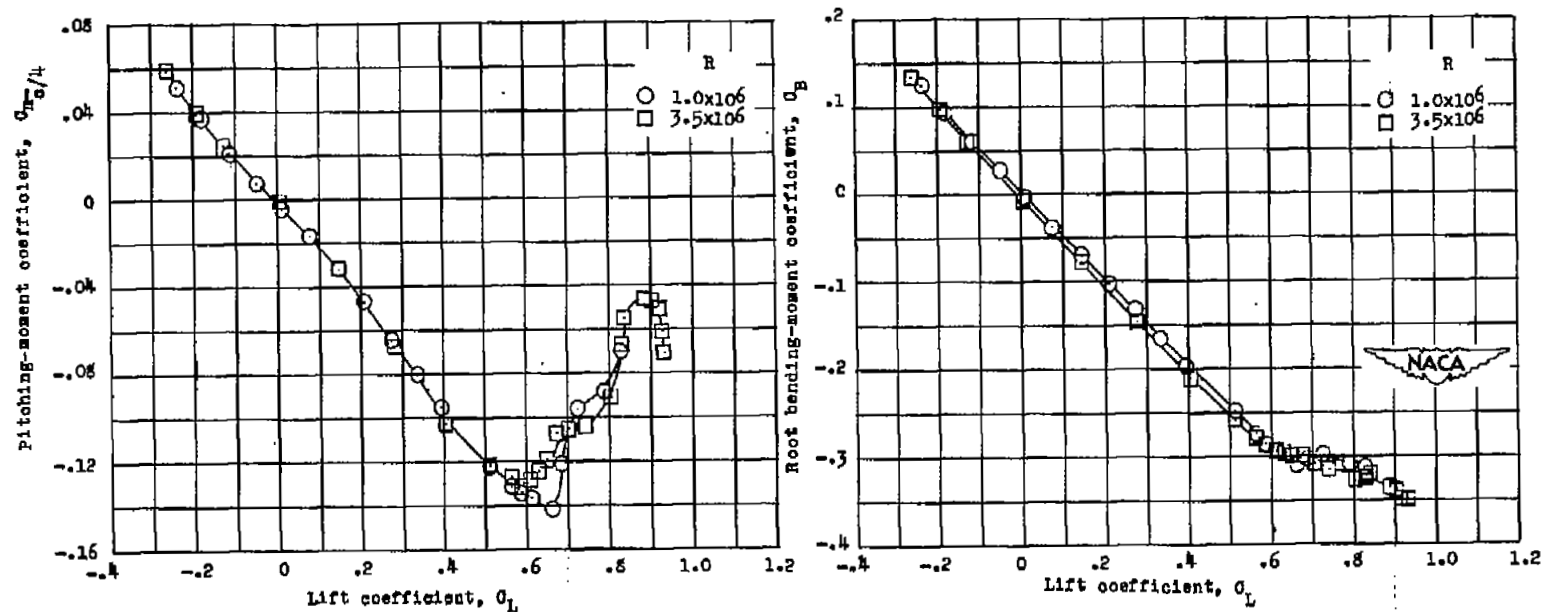
(b) Pitching moment and root bending moment.

Figure 5.- Concluded.
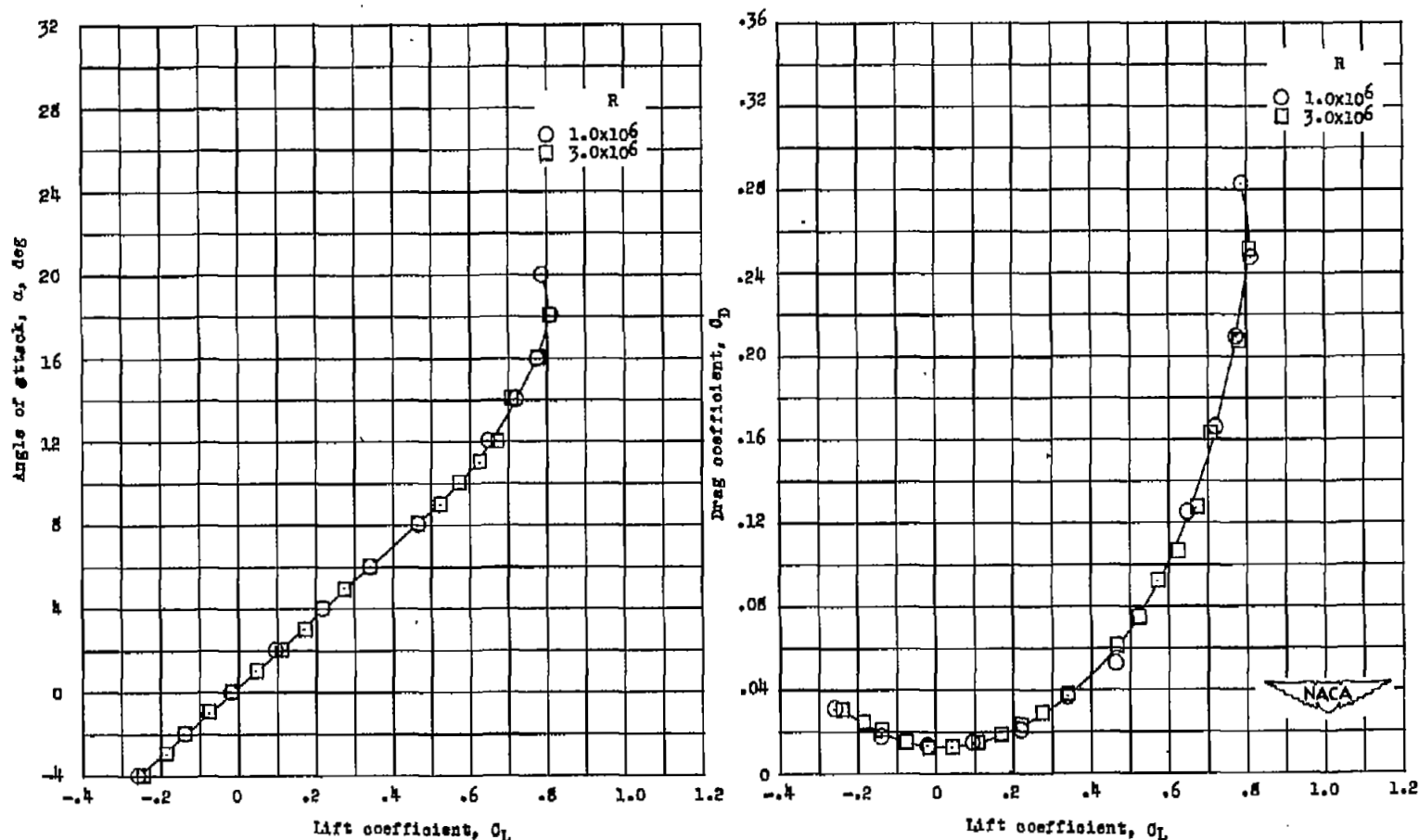
(a) Angle of attack and drag.

Figure 6.- Aerodynamic characteristics of the wing with the NACA 65A006 air-
foil section for two Reynolds numbers at a Mach number of 1.2.
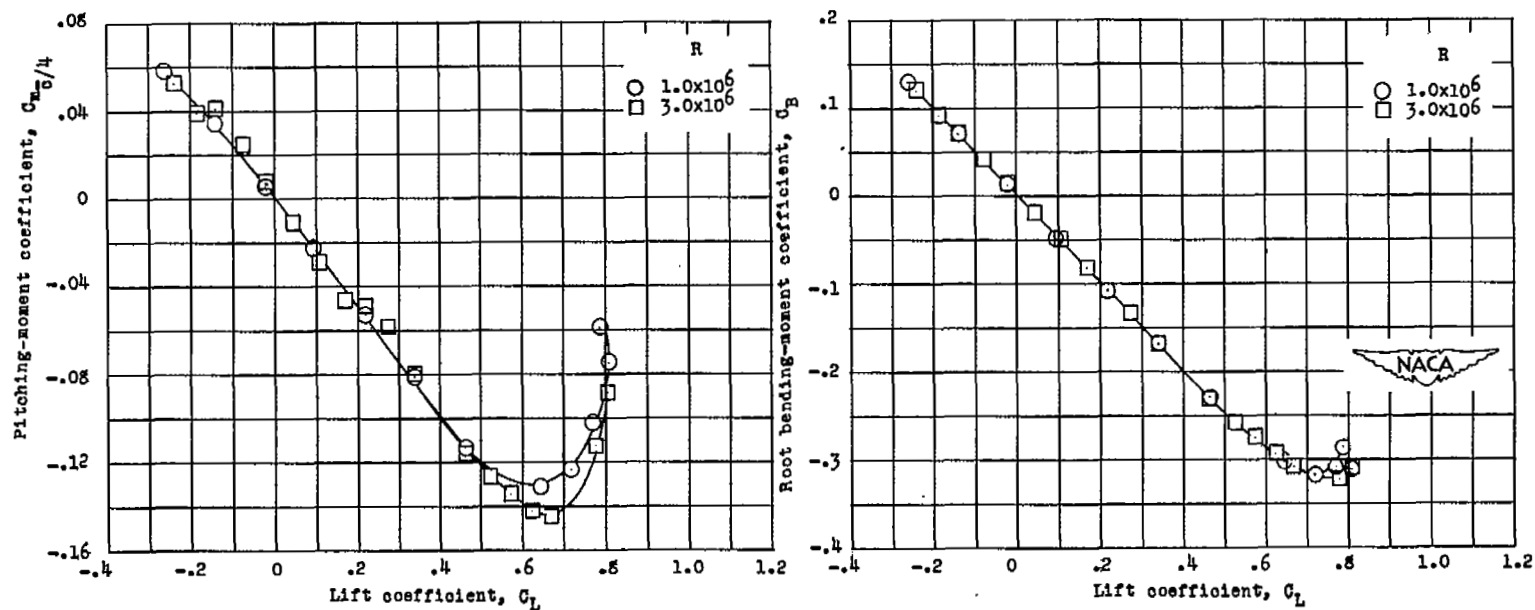
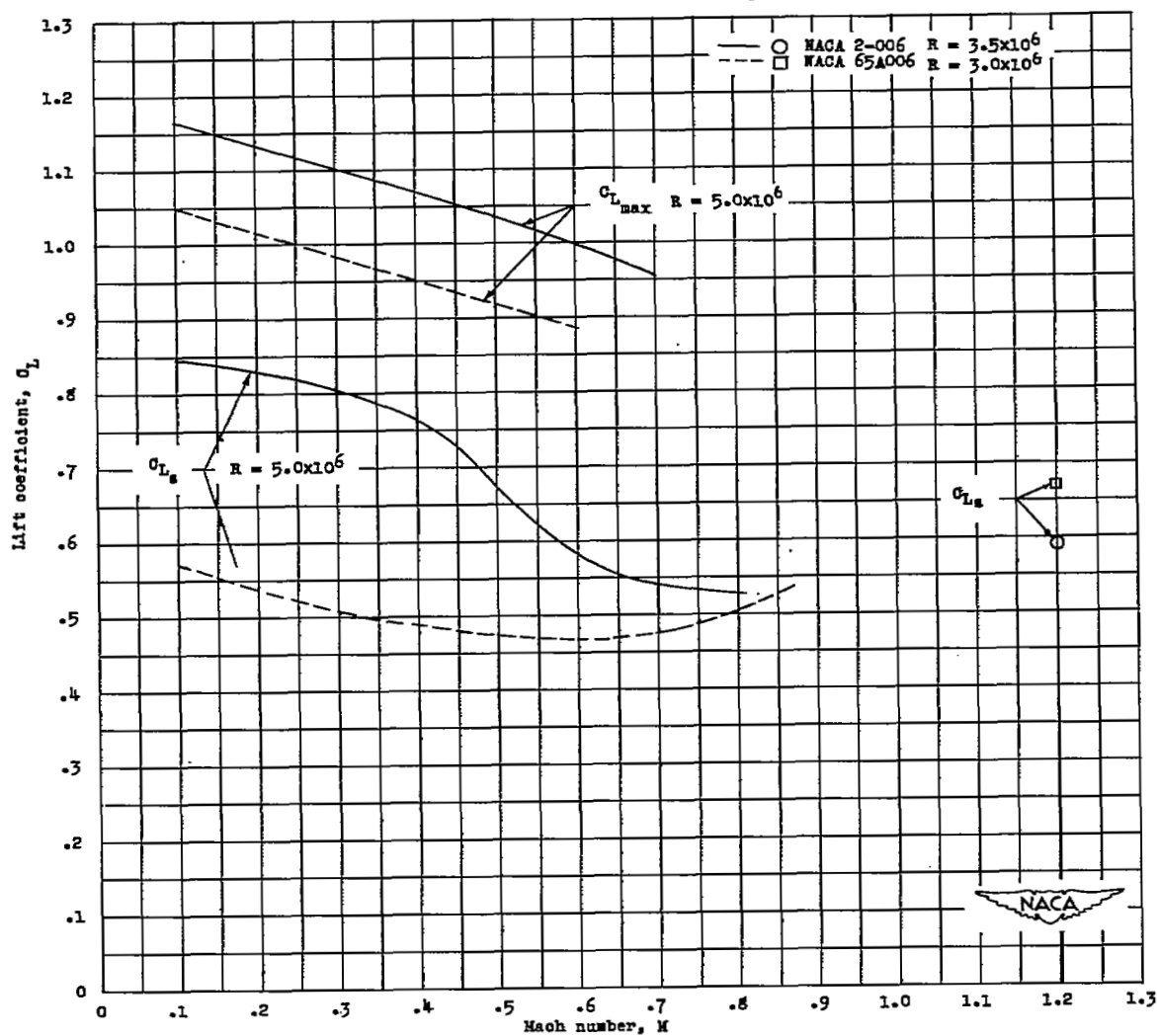(b)   Pitching moment and root bending moment.

Figure 6.- Concluded.

(a) Angle of attack and drag.

Figure 7.- Aerodynamic characteristics of two 45° sweptback wings utilizing the NACA 2-006 and NACA 65A006 airfoil sections at Reynolds numbers of 3.5×10^6 and 3.0×10^6, respectively, and a Mach number of 1.2.
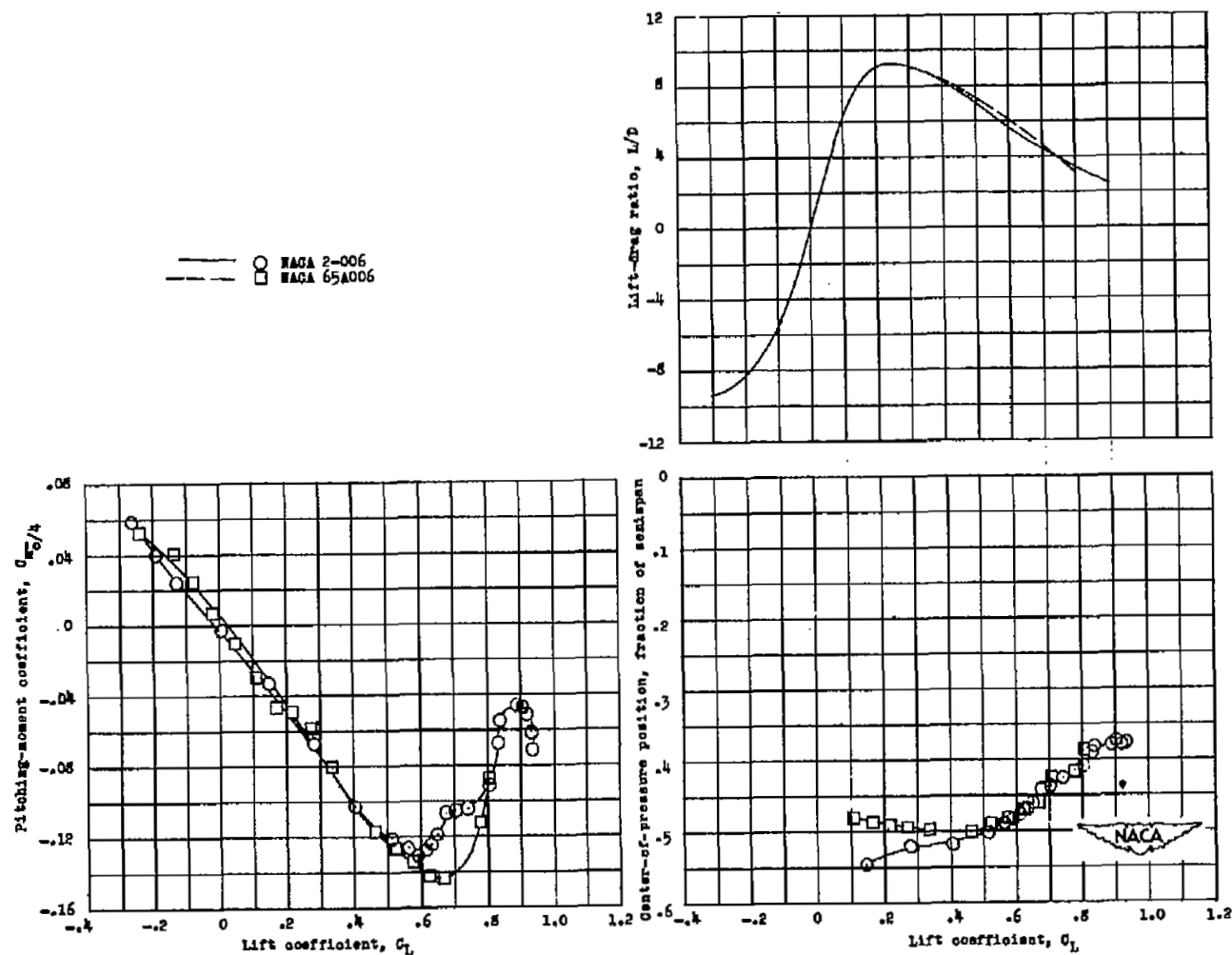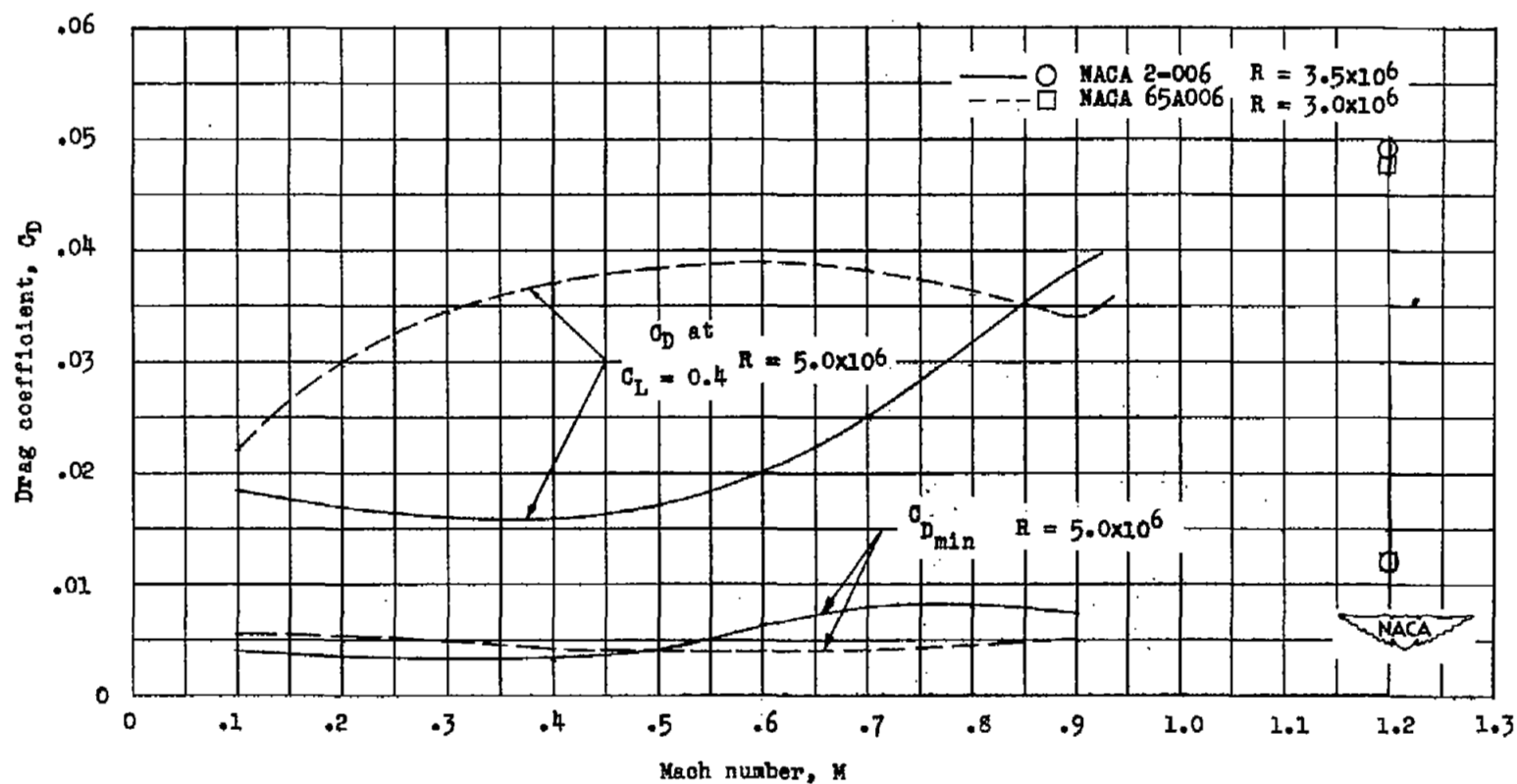
(b) Pitching moment, center of pressure, and lift-drag ratio.

Figure 7.- Concluded.

(a) Lift characteristics.

Figure 8.- Aerodynamic characteristics of two 45° sweepback wings utilizing
the NACA 2-006 and NACA 65A006 airfoil sections.

(b) Drag characteristics.

Figure 8.- Concluded.